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RESEARCH DEPARTMENT REPORT

Reduction of mush-area distortion in common-frequency m.f. transmitter networks

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Research Department, Engineering Division
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D.J. Whythe, B.Sc.(Eng.), C.Eng., M.I.E.E.

Summary

The present crowding of the medium-wave band has made it necessary for several transmitters that broadcast a common programme to share a common carrier frequency and, in many cases, their service areas considerably overlap. Daytime reception is impaired by ground-wave interference between pairs of such transmitters in regions (so-called 'mush' areas) where their field-strength ratio is less than about 10 dB. At night, mutual interference is also caused by sky-wave signals from other transmitters in the group.

The results of laboratory tests are given which assess the improvement to daytime reception that would result if the times of arrival of the two modulations were equated in these mush areas. The results of a subsequent nine-months field trial between two high-power m.f. stations are also described. They show the arrangement to be practicable and to have been sufficiently stable to maintain, without adjustment, a substantial improvement to daytime reception throughout the test period.

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REDUCTION OF MUSH-AREA DISTORTION IN COMMON-FREQUENCY MF TRANSMITTER NETWORKS

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1. Introduction

The present crowding of the medium-wave band has made it necessary for several BBC transmitters that broadcast the same programme to share a common carrier-frequency. In order to obtain the greatest coverage, using a single frequency, many of the transmitters are placed close enough to provide overlapping service areas. Under these conditions, daytime reception is impaired by mutual interference in certain so-called 'mush' areas where the field-strengths of pairs of transmitters are approximately equal. Most listeners in those areas may gain some improvement by suitably orientating their receivers but, in general, the impairment is noticeable wherever the field-strength ratio is less than about 10 dB and it may be severe where the ratio is less than about 6 dB.

In the great majority of cases, only two transmitters contribute significantly to the resultant signal under daylight conditions in any given area, but there may be other areas in which signals from more than two transmitters need to be considered. This Report describes the improvement that would result if the times of arrival of the modulation-envelopes of the two dominant signals were equated at a suitable point within the mush area. This and other techniques have previously been considered.[1,2]

2. The character of the impairment

It is shown in the Appendix that, for sinusoidal modulation, the effective modulation depth (m_1) at the receiver detector (and hence the amplitude of the audio output signal) when the carriers are in additive phase in a two-transmitter situation is given by

$$m_1 = m(1 + a^2 + 2a \cos p\tau)^{1/2}/(1 + a) \qquad (1)$$

where m is the modulation depth at the transmitter,

$p/2\pi$ is the modulation frequency,

a is the ratio of the two carrier amplitudes,

and τ is the difference between the times of arrival, at the receiving point, of the two modulations. (This assumes uniform delay at all modulation frequencies, i.e. it neglects dispersion – see Section 5.5).

Thus for this carrier-phase condition, there is never any non-linear distortion due to overmodulation at the detector but, unless τ is so small that $\cos p\tau \simeq 1$ at the highest modulation frequency, there is a linear frequency-spectrum distortion (or 'combing') over the audio-frequency band because the amplitude of the audio signal varies from m to $m(1-a)/(1+a)$ as a function of modulation frequency.

Also shown in the Appendix, the effective modulation depth when the two carriers are in subtractive phase is given by:

$$m_2 = m(1 + a^2 - 2a \cos p\tau)^{1/2}/(1 - a) \qquad (2)$$

If τ is so small that $\cos p\tau \simeq 1$ at the highest modulation frequency, the only impairment is that due to noise as the ratio of the carrier-amplitude approaches unity. If τ is appreciable, however, there will be certain modulation frequencies for which the effective modulation depth at the receiver detector is $m(1+a)/(1-a)$ and, unless either a or m is small, gross non-linear distortion will occur due to the resulting overmodulation.

In a practical situation, with transmitters using independent high-stability drives, the finite beat-frequency between the two carriers causes the phase difference between the carriers at a fixed receiving point to vary steadily between the additive-phase and subtractive-phase conditions; hence the character of the impairment to the received signal varies slowly from one of the above extremes to the other.* The effect may be regarded in terms of zones of interference, in some places spaced only one quarter-wavelength apart at the carrier frequency, that sweep slowly across the affected area at a rate depending upon the frequency difference between the two carriers. It is interesting to note that zones of bad reception (i.e. carriers subtracting) for receivers using rod or wire aerials are zones of good reception (i.e. carriers adding) for receivers using frame or ferrite-dipole aerials, and vice-versa.

If the times of arrival of the two modulation-envelopes were equated (i.e. $\tau = 0$) along a particular (hyperbolic) locus, the signal received at any point along that locus would never suffer either spectral or non-linear distortion even if the two field-strengths there were equal. The only impairment would be a worsening signal-to-noise ratio whilst the two carriers were in near-cancelling phase. There would be areas nearby, however, in which the field-strengths were either equal or nearly equal but in which the times of arrival of the two envelopes differed by up to a few hundred microseconds. In those areas the received signal would suffer, to some degree, both the spectral and the non-linear types of distortion. Thus it was necessary to assess the resulting distortion as a function of both time-delay and relative field strength, so that the effect over the whole of the service area could be predicted. For that reason, a series of laboratory tests was performed.

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* No advantage would be gained by synchronising the two carrier frequencies because, although the two fields would then remain permanently in additive phase at certain points in the mush-area, they would remain permanently in antiphase at others. For that reason reception in moving vehicles would also not be improved.

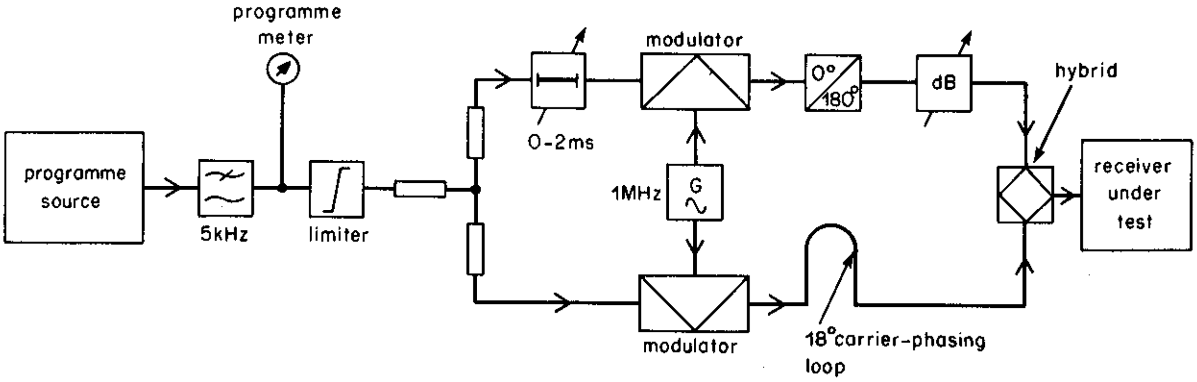

Fig. 1 - Experimental arrangement for subjective tests

3. Laboratory tests

Subjective tests were performed using the arrangement shown in Fig. 1. The programme source was a tape recording of typical Radio-1 programme, recorded with the normal 12 dB compression and 5 kHz bandwidth-restriction, and was used to amplitude-modulate two separate outputs from a 1 MHz crystal oscillator. The two modulated signals were combined and fed to the receiver under test. The amplitude of the output signal from one modulator was set such that, at the receiver, it corresponded to a field-strength of 3 mV/m, a value typical of that over the majority of the mush-areas in question. Provision was made to introduce known delays, uniform over the programme bandwidth, in the audio signal feed to the other modulator, and to attenuate its output signal by known amounts.

A preliminary series of tests was carried out using two separate carriers with a beat-frequency of one cycle in about 20 seconds and with various amplitude ratios. The results showed that the non-linear distortion that occurred during the near-cancelling carrier-phase condition was subjectively far more disturbing than either the linear combing distortion that occurred during the additive carrier-phase condition or the increase in noise level that occurred during the cancelling condition. The arrangement shown in Fig. 1, using two synchronous carriers with a constant phase difference, was therefore adopted, partly for economy in time but mainly because, with differing carrier frequencies, the very critical subtractive-carrier-phase condition occurred at different instants in the programme for the various tests and was found to lead to inconsistent results. Since it would have been unreasonably pessimistic to adopt a continuously-cancelling carrier phase (viz 180°), a phasing loop was added as shown in Fig. 1 by which a phase difference of 162° was maintained between the two carriers. Because this is 18° away from the cancelling-phase condition, the resulting distortion is that which is exceeded for 10% of the carrier-beat period (i.e. for 10% of the time).

Two experienced listeners* took part in the tests and, using a fairly good-quality, modern, battery-portable receiver, were asked to assess the quality of reception for various carrier-amplitude ratios and relative audio delays, for programme content comprising either speech (news bulletin) or music ('pop' group). Because the normal five-grade subjective impairment scale was found to be insufficient to distinguish between the gross degrees of distortion that occurred, the special scale defined below was adopted. For comparison, the nearest corresponding grades of the normal five-grade scale[3] are also shown.

Grade adopted for tests	Impairment	Corresponding five-grade scale
1	Imperceptible	5
2	Perceptible but not objectionable	4
3	Somewhat objectionable	3
4	Definitely objectionable	2
5	Very objectionable	1
6	Programme barely intelligible	1
7	Programme quite unintelligible	1

In order to study the effect of reducing the peak modulation depth at the two transmitters, the experiments were performed first with 100% peak modulation depth and then repeated with 80% peak modulation depth. The improvement that would be gained within the affected area, however, was found to be only ½ grade to 1 grade and, since that reduction of peak modulation depth would worsen the signal/noise ratio by 2 dB for all listeners throughout the whole of the service areas of both transmitters, the question of operating the transmitters at reduced modulation depth was not considered further.

The results when using 100% peak modulation depth are given in Tables 1 and 2.

The above results accord with those obtained during the preliminary tests, when the two carriers were steadily beating. It is therefore considered appropriate to use them for planning purposes and, because distortion rather than noise was by far the dominant impairment, they may be taken to apply wherever the field strength of either signal exceeds 1 mV/m, a value that has been suggested as

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* The distortions were so gross that results with sufficient accuracy could be obtained using only two listeners.

TABLE 1

Subjective grading of distortion exceeded for 10% time, using music programme

Carrier-amplitude ratio, dB	Subjective grade for audio-frequency delay equal to:						
	0	30μs	50μs	83·5μs	250μs	1 ms	2 ms
0	2	3	4	5	7	7	7
1	1·5	2·5	3	4·5	7	7	7
2	1	2	2·5	4·5	7	7	7
3	1	1	1·5	3·5	5·5	7	6
4	1	1	1	3	4·5	6	4·5
5	1	1	1	2	3·5	5	3
6	1	1	1	1	2·5	4	2
7	1	1	1	1	2	3	2
8	1	1	1	1	2	2	1·5
9	1	1	1	1	1	1	1

TABLE 2

Subjective grading of distortion exceeded for 10% time, using speech programme

Carrier-amplitude ratio, dB	Subjective grade for audio-frequency delay equal to:						
	0	30μs	50μs	83·5μs	250μs	1 ms	2 ms
0	1	2	3·5	4·5	6	7	7
1	1	2	3	4·5	6	7	6
2	1	1·5	2	3	6	6·5	5·5
3	1	1	1·5	1·5	4	6	4·5
4	1	1	1	1	3	5·5	3·5
5	1	1	1	1	2·5	4·5	3
6	1	1	1	1	2	3·5	2·5
7	1	1	1	1	1·5	2·5	2·5
8	1	1	1	1	1	2	1·5
9	1	1	1	1	1	1·5	1·5
10	1	1	1	1	1	1	1

representing the limit of the service area.[4] The results show that the impairment is slightly worse for a music programme than for a speech programme. The values shown in Table 1 may therefore be taken to represent the worst case.

4. Improvement to reception

4.1. Improvement under idealised conditions

The BBC transmitters at Droitwich and Brookmans Park (radiating the Radio-1 programme at 1214 kHz, 247 m) are known to cause this type of mutual interference in an area about 60 – 65 km from Brookmans Park, where the field strength from each transmitter is about 3 mV/m. Under the present arrangements for feeding programme to the transmitters, the times of arrival of the two modulation-envelopes differ by about 2 ms in the area concerned. Idealised field-strength-ratio contours of the two transmitters are drawn in Fig. 2, assuming that the equi-field condition occurs at 62·5 km from Brookmans Park* and also assuming that the field strength of each transmitter varies inversely as the square of the distance. The contours are drawn to the assumed circular limits of the two service areas, namely 1 mV/m. Hyperbolae are also drawn in Fig. 2 which show the intervals between the times of arrival of the two modulation-envelopes over the affected area, assuming that suitable delay (approx. 2 ms) has been inserted in the programme feed to the Brookmans Park transmitter so as to equate the times of arrival of the two modulations at the point on the straight line joining the two transmitters at which their two field strengths are equal.

Based on the results for music programme shown in Table 1, Fig. 2 shows the considerable proportion of the

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* The transmitter power at Brookmans Park is greater than at Droitwich but the equal-field condition occurs at this distance because of the directional properties of the aerial at Brookmans Park. For the idealised conditions shown in Fig. 2 an omnidirectional aerial is assumed at Brookmans Park, fed by a transmitter of correspondingly reduced power.

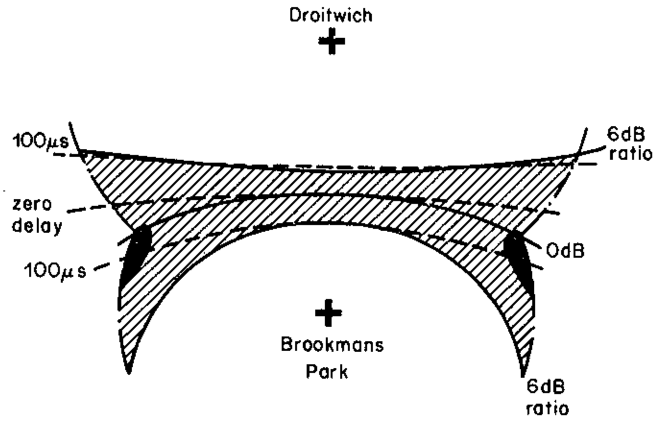

Fig. 2 - Reduction of distortion within idealised service area

Regions in which distortion for music programmes would be 'definitely objectionable' or worse for 10% of the time. (See Table 1.)
▨ without delay correction
■ with delay correction

— — — relative time-delay contours
——— field-strength ratio contours
—·— limit of service area (1 mV/m contour)

mush area over which reception would be improved under these idealised conditions.

4.2. Improvement under practical conditions

In practice, the proportion of the mush area over which reception is greatly improved is likely to be less than that shown in Fig. 2 because the practical field-strength contours are not as regular in shape as the idealised contours. Furthermore, the long-term stability of both the field-strength contours and the delays in the programme circuits may not be sufficient to maintain the optimum condition over very long periods. In addition, contributions from other transmitters in the common-frequency group* may be significant in certain parts of the mush area. The impairment that they might cause to reception was not assessed as part of the laboratory tests. It should also be noted that if three or more transmitters form a closed 'chain' of mush areas there will generally be one mush area to which the delay-equalisation technique described in this Report cannot be applied.

On the other hand, the technique would bring improvement to daytime reception, in varying degrees depending upon position, to all parts of each mush area without causing any degradation elsewhere. A field trial was therefore conducted in order to gain information in a practical situation.

5. Field trial

5.1. General

The purposes of the field trial were to assess the feasibility of implementing the arrangement, the resulting improvement to reception, its stability with time, and the demands that it imposed operationally.

It was decided to conduct the field trial between the Radio-1 (1214 kHz) transmitters at Droitwich and Brookmans Park (see Section 4). Reception would most probably have been improved over the greatest area if the two modulations were co-phased at the point on the line joining the transmitters where their two field strengths were equal. Preliminary measurements of the field-strength ratio (performed as described in Section 5.2), however, had shown the equal-field-strength locus to pass near Bedford, which lies some 25 km East of the line joining the transmitters, and it was decided to co-phase the modulations in that vicinity in order to provide the maximum improvement for the greatest number of listeners.

In the future, the modulation-frequency at all BBC medium- and low-frequency transmitters will be restricted by a filter giving progressive attenuation at frequencies above 5 kHz. Furthermore, the i.f. filters in virtually all m.f. and l.f. receivers in current use in the UK heavily attenuate the transmission sidebands that correspond to modulation frequencies above about 4 kHz. It was therefore assumed that equalisation of modulation delays at frequencies up to only 4 kHz would be adequate.

5.2. Measurement of field-strength ratio

For the field trial, field-strength measurements were required to determine only the locus along which the Radio-1 field strengths from Brookmans Park and Droitwich were equal. With that information, the optimum point could be chosen at which the modulation delays should be equated, and the path could also be decided along which subsequent assessments should be made of the overall long-term stability of the arrangement.

Such measurements could readily be made by using a receiver with an omni-directional aerial and measuring, using a pen recorder, the max/min ratio of the resultant carrier amplitude as it varied over a carrier-beat cycle. From a knowledge of this max/min ratio, the ratio of the two individual field-strengths could be deduced. A crystal filter tuned to 1214 kHz (the measured response/frequency characteristic of which is shown in Fig. 3) was made and inserted between the aerial and the receiver in order to remove the sidebands from the incoming signals and thus to improve the accuracy of measurement at the minima.

The equal-field-strength locus was found to pass near Bedford and, as stated in Section 5.1, it was decided to equate the two modulation-envelope timings at a reference site (map reference TL 056442) on the locus in that vicinity in order to provide the maximum improvement for the greatest number of listeners. The long-term stability of the daytime field-strength ratio was assessed over a nine-

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* The term 'common-frequency group' is preferred rather than the more commonly-used term 'synchronous group' because the carriers, although at nominally identical frequencies, are not synchronised.

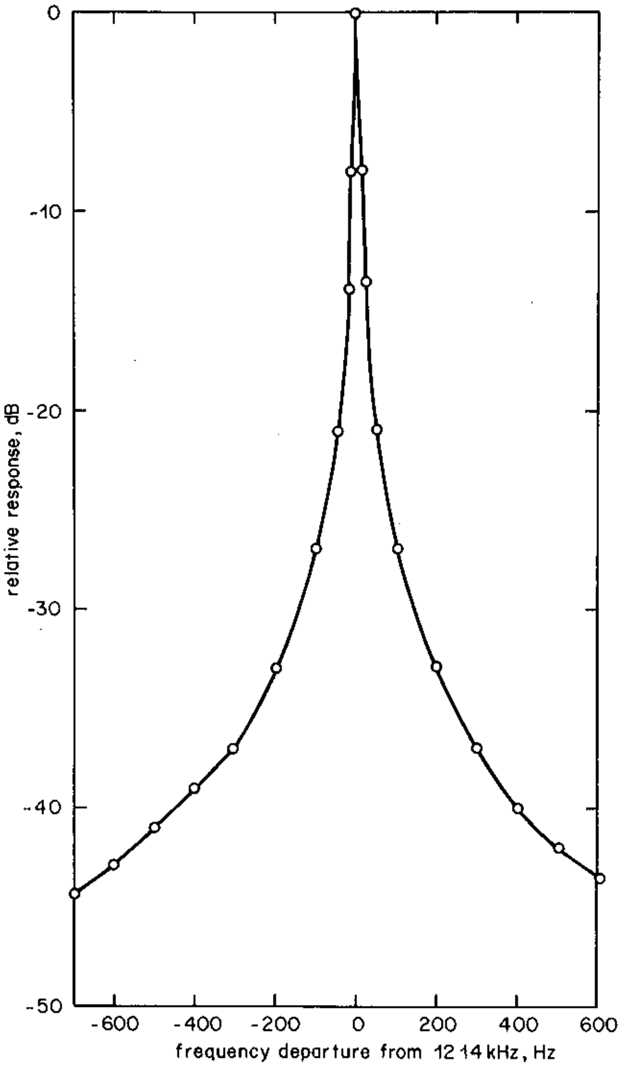

Fig. 3 - Frequency response of crystal filter

month test period by making repeat measurements at the reference site and at two others (map reference TL 412619 and SP 665358) along the locus from Cambridge to Buckingham. The results are given in Section 5.7.1.

5.3. Delay tolerance

Table 1 shows that, for 1 dB carrier-amplitude ratio, the distortion became 'perceptible' when the two modulation delays differed by more than about 30 μs. This result was obtained in the laboratory using delay lines having negligible dispersion (i.e. their delays were constant over the modulation bandwidth). Thus the delay difference of 30 μs corresponded to a phase difference that varied linearly with modulation frequency from 1·1° at 100 Hz to 44° at 4 kHz. In practice, however, the delay introduced by programme circuits is accompanied by dispersion (see Section 5.5) and the phase shift is not proportional to frequency, particularly at low modulation-frequencies.

When modulation-delay equalisation was recently tried in Australia,[5,6] mixed tolerances were adopted such that the delays were equated to within ±25 μs at modulation frequencies above 1 kHz and the phases equated to within ±9° at frequencies below 1 kHz.

For the present work it was considered best to specify the delay tolerance in terms of a maximum permissible phase difference between the two modulations at all modulation frequencies. It was likely that the distortion encountered during the laboratory tests was most noticeable on components of the modulation at frequencies in the range 1 kHz to 2 kHz, at which a delay difference of 30 μs would correspond to a phase difference of 10° to 20°. It was considered at the time that this would be difficult to achieve and, for the field test, it was considered reasonable to aim for phase equalisation to within ±30° at all modulation frequencies from 50 Hz to 4 kHz. In the event, phase equalisation to within ±20° was maintained.

5.4. Delay measurement

In order to provide the phase equalisation defined in Section 5.3 it was first necessary to measure the phase difference, as a function of modulation frequency, between components of the programmes travelling by the two paths from the programme-origination point to the two transmitters, and hence to the listener's receiver. This measurement cannot readily be made directly during daylight hours because the programme modulation would be unsuitable; nor can it be made directly after dark because of interference from the sky-wave. It must therefore be made indirectly, by measuring the individual phase-characteristics of the programme-signal circuits to the two transmitters, and of the two transmitters themselves, and allowing for the propagation times from the two transmitters to the receiving point. The measurement is not straightforward, however, because of the large separations between the various measuring points.

In Australia,[5] a method of measurement involving a spare two-way programme circuit to each transmitter was adopted, but it was considered to be more convenient in the UK to measure the phase characteristic of each programme circuit relative to a common reference, namely the signal received from a v.h.f. transmitter.

Thus the difference between the phase characteristics of the programme circuits from the programme origination point at Broadcasting House to the m.w. transmitters at Brookmans Park and Droitwich was measured as a function of modulation frequency, out of programme hours, by feeding tone from Broadcasting House to each transmitter in turn, and also to one of the v.h.f. f.m. transmitters at Sutton Coldfield. The phase of the tone incoming to each m.w. transmitter was measured relative to that of the demodulated signal received from Sutton Coldfield and each result was corrected for the propagation delay from Sutton Coldfield. The two resulting phase characteristics were then subtracted and, to that difference, was added the difference between the measured phase characteristics of the two m.w. transmitters and also the difference in propagation times from Brookmans Park and Droitwich to the reference site near Bedford where the two modulations were to be co-phased. The resultant phase characteristic, shown in Fig. 4, represents the correction required in the programme feed to Brookmans Park.

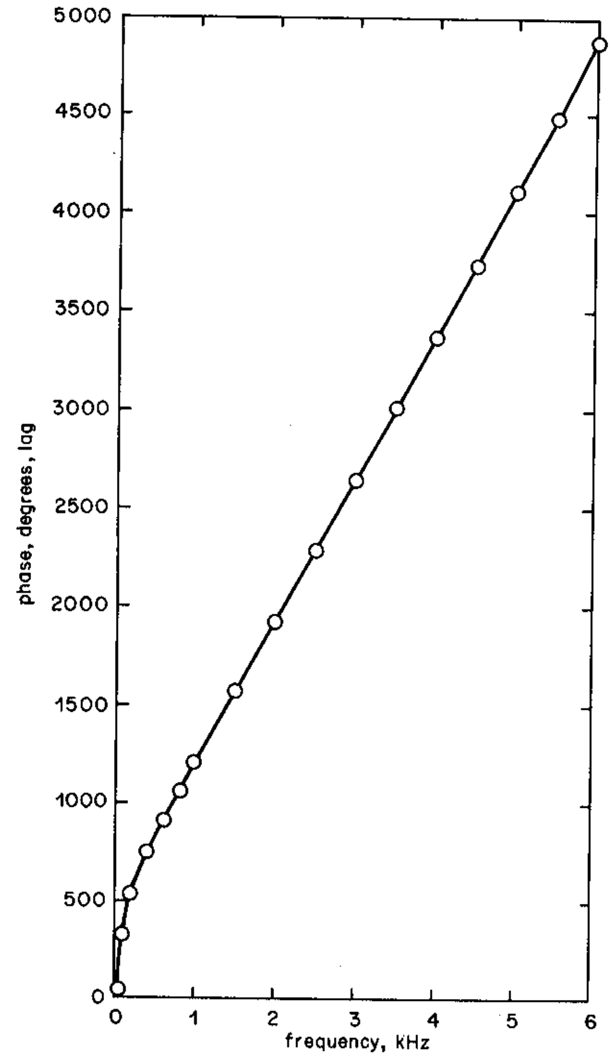

Fig. 4 - Overall phase correction required in programme feed to Brookmans Park

5.5. Delay correction

Preliminary phase measurements on typical programme circuits showed that there is little dispersion (i.e. the group delay* is substantially constant) over the middle range of audio frequencies. Appreciable dispersion at frequencies below 400 Hz is caused by repeater amplifiers and other terminal equipment but it takes a form that can readily be corrected by means of simple circuits of the type shown in Fig. 5. Very considerable dispersion arises at high frequencies if part of the programme circuit consists of inductance-loaded lines but, provided the cut-off frequency of the loaded sections exceeds about 12 kHz, overall dispersion-correction to within ±30° is straightforward up to 4 kHz.

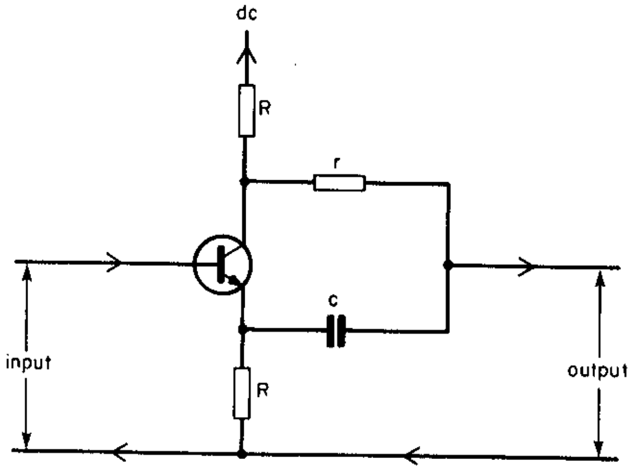

Fig. 5 - Network for low-frequency dispersion correction

In addition to dispersion correction, the field trial required delay-correction to be provided which could be set to any value up to 3 ms* and which was stable in the long term to within ±5 μs. This could conveniently be provided by means of a 'bucket-brigade' delay circuit which is now available in integrated-circuit form. Such a device accepts and delivers an analogue signal but the delay which it introduces is determined by the frequency of an oscillator which 'clocks' samples of the input signal, through storage elements, to the output. Accordingly, the required phase characteristic, shown in Fig. 4, was resolved into a phase characteristic, linear with frequency, corresponding to about 2 ms delay, plus the dispersion characteristic shown in Fig. 6. The whole was realised by using seven sections of the type shown in Fig. 5 together with a bucket-brigade delay module, clocked at about 132 kHz.**

5.6. Preliminary tests

The phase correction network was inserted at Broad-

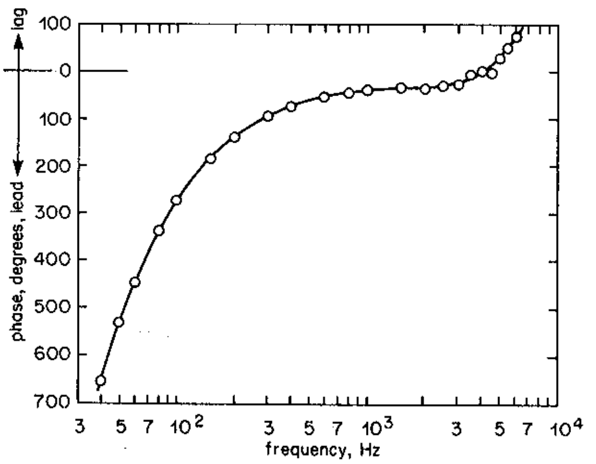

Fig. 6 - Dispersion characteristic

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* Group delay here is defined by $d\phi/d\omega$ where ϕ is the phase angle at frequency $\omega/2\pi$.

* This applies if only the transmitters at Droitwich and Brookmans Park are considered. Some 7 ms would be required if the more distant transmitters in the common-frequency group were included.

** The fully-engineered version of the complete phase-correction equipment was designed by Mr. N.H.C. Gilchrist.

casting House in the Radio-1 programme feed to Brookmans Park on 22nd April 1974. As a precaution, shortly before inserting the network, a test signal comprising a series of uni-directional pulses (bandwidth-restricted to 5 kHz) was sent to both Brookmans Park and Droitwich in order to establish, from the waveshapes of the modulated carriers, that no adventitious phase-reversal had occurred in either of the programme circuits since the time when their phase characteristics were measured. It was found, by judging the quality of the programme received at the reference site whilst various clocking-frequencies were applied to the bucket-brigade delay module, that it was possible to optimise subjectively the delay for that particular site to within about ±15 μs. Judged in that way, the optimum clocking frequency of 132 kHz was confirmed.

The quality of the received signals with and without the correction was assessed along the region of the equal-field-strength locus from Cambridge to Thame. The assessments were made using a receiver fitted with a vertical rod aerial in order to gain no discrimination against either of the two transmitted signals and hence for the assessments to represent the worst case.

The improvement brought about by the phase correction was found to be substantial, although reception was not perfect even at the reference site. There was no evidence of the linear 'combing' distortion (see Section 2) at any of the test sites but, at several sites where the field-strength ratio was 1·5 dB or less, some residual non-linear distortion that would be graded 4 on the scale given in Section 3 was evident during the period of carrier near-cancellation. This would be expected at the assumed limits of the service area, but it was not expected to be so severe near the reference site. The reason for it has not been investigated but it may have been caused, at least in part, by small differences in the modulation depth or dynamic characteristics at the transmitters.

It was therefore decided to retain the phase-correction for a further nine-month test period in order to assess both the overall stability of the arrangement, and the demands that it imposed operationally. A crystal-controlled clocking-oscillator was provided for the delay module in order to stabilise its delay; a test routine using the uni-directional pulses was also adopted operationally in order to check each morning the polarity of the two programme circuits before transmissions began.

5.7. Results of extended tests

5.7.1. Field-strength measurements

Check-measurements of the field-strength ratio

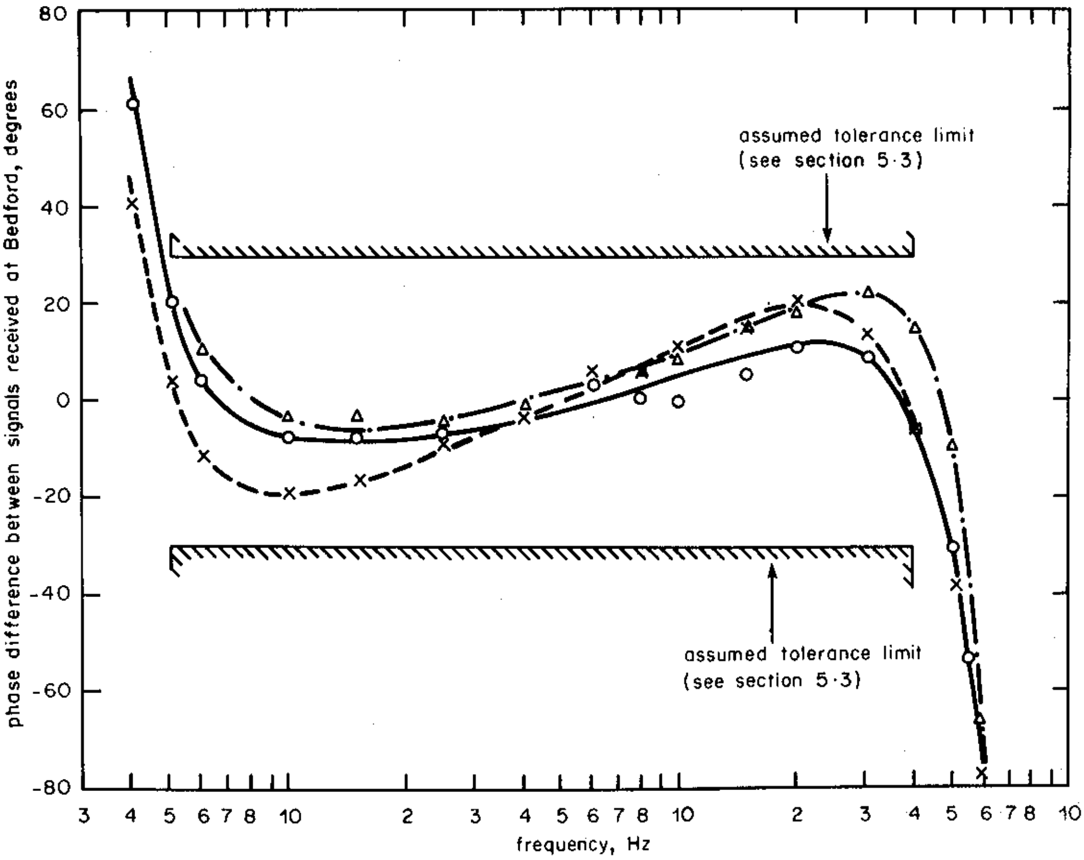

Fig. 7 - Phase difference between signals from Brookmans Park and Droitwich received at Bedford

×— —× Deduced from measurements March 1974

○——○ Deduced from measurements October 1974

△—·—△ Deduced from measurements December 1974 (using the method described in Section 5.2), and the quality of the received signal, were made during daylight hours at the reference site near Bedford and also at the test sites near Cambridge and Buckingham (see Section 5.2) during April, June, July, August, October and December 1974.

The ratio between the Brookmans Park and Droitwich field-strengths was about 1·5 dB at each of the three test sites and it remained constant to within about ±1 dB throughout the above period of measurements. At the test sites near Cambridge and Bedford, where only the above two signals were present, their ratio could be measured with an accuracy of about ±0·1 dB. At the test site near Buckingham, however, a third signal was found to be present with field strength about 20 dB lower than either of the other two. By arranging for its frequency to be very slightly changed it was identified as that from the common-frequency transmitter at Washford. Its field strength was found to vary by about ±3 dB during the period of measurements. Its presence reduced the accuracy of measurement of field-strength ratio to about ±0·5 dB at the Buckingham site, but that was considered adequate for the purpose.

5.7.2. Stability of modulation-phase correction

The difference between the phase characteristics, as a function of frequency, of the programme circuits from Broadcasting House to Brookmans Park and Droitwich was first measured (as described in Section 5.4) during March 1974. The phase-correction equipment was installed at Broadcasting House during April 1974. The difference between the phase characteristics of the two programme circuits was re-measured in the same way both with and without the phase-correction equipment in circuit, during October and December 1974.

The results are shown in Fig. 7 in terms of the phase difference, as a function of frequency, between the two modulations as received at the reference site at Bedford with the phase correction equipment in circuit. The programme circuit from Broadcasting House to Droitwich became faulty, and was handed back to the Post Office for repair, on at least two occasions* during the period April to December 1974. After each repair it was checked and re-equalised by Communications Department in the normal way but no attention was paid to possible changes in its phase characteristic. Nevertheless, the results shown in Fig. 7 demonstrate that, throughout the test period, the phase difference between the two circuits remained within the tolerances that are considered likely to provide good improvement to daytime reception.

5.7.3. Quality of reception

The quality of reception was assessed at each of the three test sites (see Section 5.2), using a receiver with a vertical rod aerial, during April, June, July, October and December 1974. The substantial improvement to reception originally provided by the phase correction (see Section 5.6) was found to be consistently maintained throughout the test period. The presence of low-level signals from other stations in the common-frequency group (e.g. from Washford, see Section 5.7.1) appeared, if anything, generally to blur the carrier minima when the two dominant carriers were in subtractive phase and hence to lessen, rather than to increase, the distortion of the resultant received signal at those instants. This opinion is in agreement with the results of tests conducted in the USSR[7] from which a protection ratio of 7 to 8 dB was proposed for two transmitters but only 6 dB for the case of three transmitters.

5.7.4. Demands imposed operationally

No adjustments were made to the phase-correction equipment, nor did any fault develop, during the test period. The polarity of the two programme circuits was checked before transmission each morning (see Section 5.6). The only other demand imposed operationally was the need to remove the phase-correction equipment from the programme feed to Brookmans Park when either that programme circuit or the one to Droitwich became faulty.

6. Conclusions

This work has shown that the severe impairment to reception caused, in certain areas, by mutual interference between common-frequency medium-wave transmitters can, during daylight hours, be substantially reduced by suitably phasing the programme modulation fed to each transmitter. The area over which this improvement can be gained is determined by the shapes of the field-strength contours in the overlapping regions; the results of laboratory tests are given in Section 3 by which the resulting improvement in terms of service area and population may be assessed for particular pairs of transmitters, given their field-strength contours.

The results of a nine-month field trial of the arrangement (between the Radio-1 m.w. transmitters at Brookmans Park and Droitwich) are also given. They show the arrangement to be both very practicable and sufficiently stable to maintain a substantial improvement to daytime reception throughout the test period. The additional equipment required no attention throughout the test period and the arrangement imposed very little extra demand operationally.

It must be emphasised that the arrangement will improve reception only during daylight hours; the variable nature of the skywave precludes any reliable improvement after dark. Furthermore, the maximum improvement to daytime reception will not be so great in regions where more than two transmitters contribute significantly to the received signal. Nevertheless, the arrangement could be made to improve daytime reception throughout all the service areas without causing any degradation elsewhere by day or by night, the improvement being much greater in some areas than in others.

As a result of this work it is expected that modulation-phase equalisation will be retained between the Radio-1 transmitters at Brookmans Park and Droitwich. Consideration is now being given to an extension that will include the Radio-1 transmitters at Moorside Edge and Washford, thus dealing with the four transmitters in England from which the Radio-1 service is most seriously affected by mush-area distortion.

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* On one of the occasions the circuit developed a major fault that continued for nearly four weeks.

7. Acknowledgements

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8. References

1. Synchronised groups of transmitters in l.f. and m.f. broadcasting. EBU Tech. 3210, August 1974.
2. BELL, C.P. Considerations of synchronised networks. I.T.U. Seminar on the planning of broadcasting systems, Sao Paulo, June 1973.
3. Method proposed for the subjective assessment of the quality of sound in broadcasting and of the performance of sound-programme transmission systems. Report 623, CCIR, Geneva, 1974.
4. PHILLIPS, G.J. Quality criteria, protection ratios, and protected field strengths. BBC Engineering, No. 97, March 1974, pp. 16 – 20.
5. SUBOCZ, M. *and* YELVERTON, W.A. Measurement of delay on programme lines to synchronous transmitters at Eidsvold and Pialba, Queensland. Res. Lab. Rep. No. 6088, P.M.G.'s Department H.Q. Australia, 1967.
6. MEDLIN, N.J. The application of engineering planning principles to a specific m.f. broadcasting project. I.T.U. Seminar on the planning of broadcasting systems in Asia, Jakarta, November 1973.
7. Radio frequency protection ratio for synchronised broadcasting transmitters. Report 459-1, CCIR, Geneva, 1974.

Appendix

Analysis of two-signal reception with common-frequency working

For sinusoidal modulation, the combined signal received from two transmitters can be represented by

$$E = (1 + m \sin pt) \cos \omega t + a[1 + m \sin p(t - \tau)] \cos (\omega t + \phi) \tag{3}$$

where m = modulation depth
$p/2\pi$ = modulation frequency
$\omega/2\pi$ = carrier frequency of one transmitter (to be termed the 'reference transmitter')
a = ratio of the carrier amplitudes
τ = difference between the times of arrival, at the receiving point, of the two modulations
and ϕ = instantaneous phase difference between the two carriers at the receiving point. This is given by

$$\phi = \theta + bt \tag{4}$$

where θ is a constant phase difference and bt is a phase difference which increases progressively with time at a rate proportional to the difference frequency between the two carriers.

For simplicity, Equation (3) may be rewritten as

$$E = x \cos \alpha + y \cos \beta \tag{5}$$

where $x = (1 + m \sin pt)$
$\alpha = \omega t$
$y = a[1 + m \sin p(t - \tau)]$
and $\beta = (\omega t + \phi)$

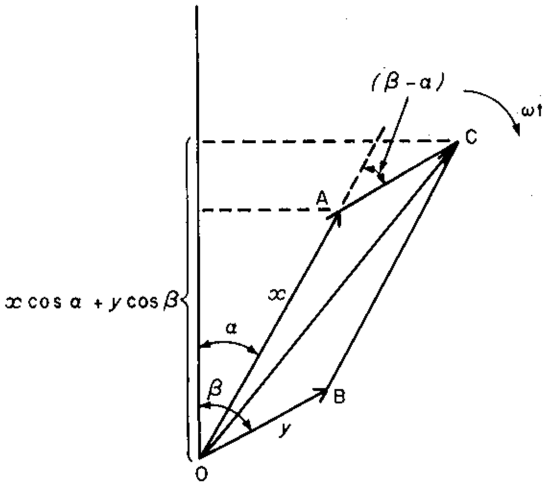

Fig. 8 - Vector representation of Equations (3) and (5)

The significance of this expression is made clear in the vector diagram of Fig. 8 in which OC represents the vector sum of the two received signals, OA and OB. These two signals are both varying in amplitude according to their modulations, their phase difference $(\beta - \alpha)$ is steadily increasing, according to the difference in carrier frequency between the two transmitters, and the entire diagram is rotating at ω, the angular carrier frequency of the reference transmitter.

The envelope of the combined signal (E) is given by

$$V = [x^2 + y^2 + 2xy \cos (\beta - \alpha)]^{1/2} \tag{6}$$

and, since $(\beta - \alpha)$ varies at infra-audio rate (e.g. less than 2π radians per second), the resultant modulation conditions can be studied for certain fixed values of $(\beta - \alpha)$, recognising that the envelope will vary steadily from one to the other of these conditions over a period of several seconds.

Condition 1: $(\beta - \alpha) = 0$

This corresponds to carrier addition, whereupon

$$V = x + y = (1 + a) + m \sin pt + am \sin p(t - \tau) \qquad (7)$$

Since τ is constant with time, this may be re-written as

$$V = (1 + a) + m_1{}' \sin pt \qquad (8)$$

where

$$m_1{}' = m(1 + a^2 + 2a \cos p\tau)^{½} \qquad (9)$$

The presence of the signal from the second transmitter increases the mean carrier level (over the period of the modulation) from 1 to $(1 + a)$ and the effect of the receiver a.g.c., in correcting for this, is to make the amplitude of the audio output signal equal to

$$m_1 = m(1 + a^2 + 2a \cos p\tau)^{½}/(1 + a) \qquad (10)$$

For all carrier ratios (a) and modulation delays and frequencies $(p\tau)$, the effective modulation depth (m_1) of the resultant signal at the detector can never exceed m when the carriers are adding. Thus there is never any non-linear distortion due to overmodulation at the detector but there is a linear spectral distortion (or combing) over the audio band in so far that the depth of modulation (and hence the amplitude of the audio output signal) varies, as a function of $p\tau$, from m at values of $p\tau$ equal to 0, 2π, 4π etc. to $m(1 - a)/(1 + a)$ at values of $p\tau$ equal to π, 3π, 5π, etc. It is interesting to note here that the depth of this combing is equal to $(1 - a)/(1 + a)$ independently of m, so the degree of linear distortion which occurs during the period of carrier addition is independent of the modulation depth.

Condition 2: $(\beta - \alpha) = \pi$

This corresponds to carrier subtraction, whereupon

$$V = x - y = (1 - a) + m \sin pt - am \sin p(t - \tau) \qquad (11)$$

and, as before, this may be written as

$$V = (1 - a) + m_2{}' \sin pt \qquad (12)$$

where

$$m_2{}' = m(1 + a^2 - 2a \cos p\tau)^{½} \qquad (13)$$

The action of the receiver a.g.c. is to make the amplitude of the audio output signal equal to

$$m_2 = m(1 + a^2 - 2a \cos p\tau)^{½}/(1 - a) \qquad (14)$$

If τ is very small such that $\cos p\tau \simeq 1$ at all modulation frequencies, the effective modulation depth at the detector (m_2) is equal to m and there is no distortion but, as the carrier ratio approaches unity, an increase in noise level occurs dur to the action of the receiver a.g.c. and, of course, the effective carrier level may fall below the a.g.c. range.

If τ is appreciable, there will be certain modulation frequencies at which $\cos p\tau = -1$, and the effective modulation depth at the detector will be equal to $m(1 + a)/(1 - a)$. Gross non-linear distortion will occur whenever this function exceeds unity and, for carrier ratios (a) less than 6 dB, it will do so whenever the modulation depth of the programme (m) exceeds 33%.

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